

UCN Storage Time and Decay Product Identification Tests at NIST

S.N. Dzhosuyk, L. Yang, A. Copete, and J.M. Doyle, Harvard University

M. Cooper, P. Barnes, S.K. Lamoreaux, and S. Penttila, LANL

R. Golub and E. Korobkina, HMI; M.E. Hayden, Simon Fraser University

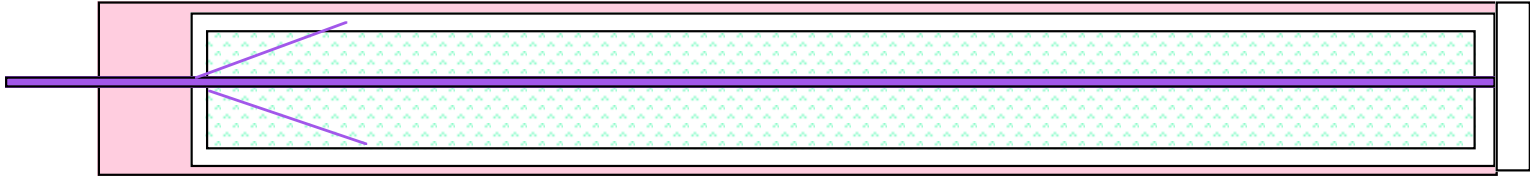
J.-C. Peng, UIUC; A.Q. Ye, Duke University

A.K. Thompson, NIST; P.R. Huffman, NC State/NIST

Objectives

- Characterize the storage time of UCNs in an acrylic cell coated with dTPB/dPS
- Quantify the efficiencies we should expect when using the particle ID techniques developed at HMI
- Measure the T^7 dependence of the 2-phonon scattering process.

Storage Time Tests



- cell dimensions:
OD = 3.25", ID = 2.25",
WT = 0.5", length 28"
- Thickness of He in front of the cell $\approx 2''$
- Thickness of the entrance window 1/16"
- dTPB coating - ERDA analysis showed the coating thickness is $\approx 9\text{-}10\ \mu\text{m}$

Neutron beam $\lambda = 0.89\ \text{nm}$,

Intensity $N \approx 6500\ \text{n/s}$ before entrance window

Transmission $\approx 30\ \%$ at 300 K

Inelastic scattering is estimated to contribute $\approx 50\ \%$ (typical value per proton $\sigma_{ie} \approx 6\ \text{b}$ for thermal neutrons)

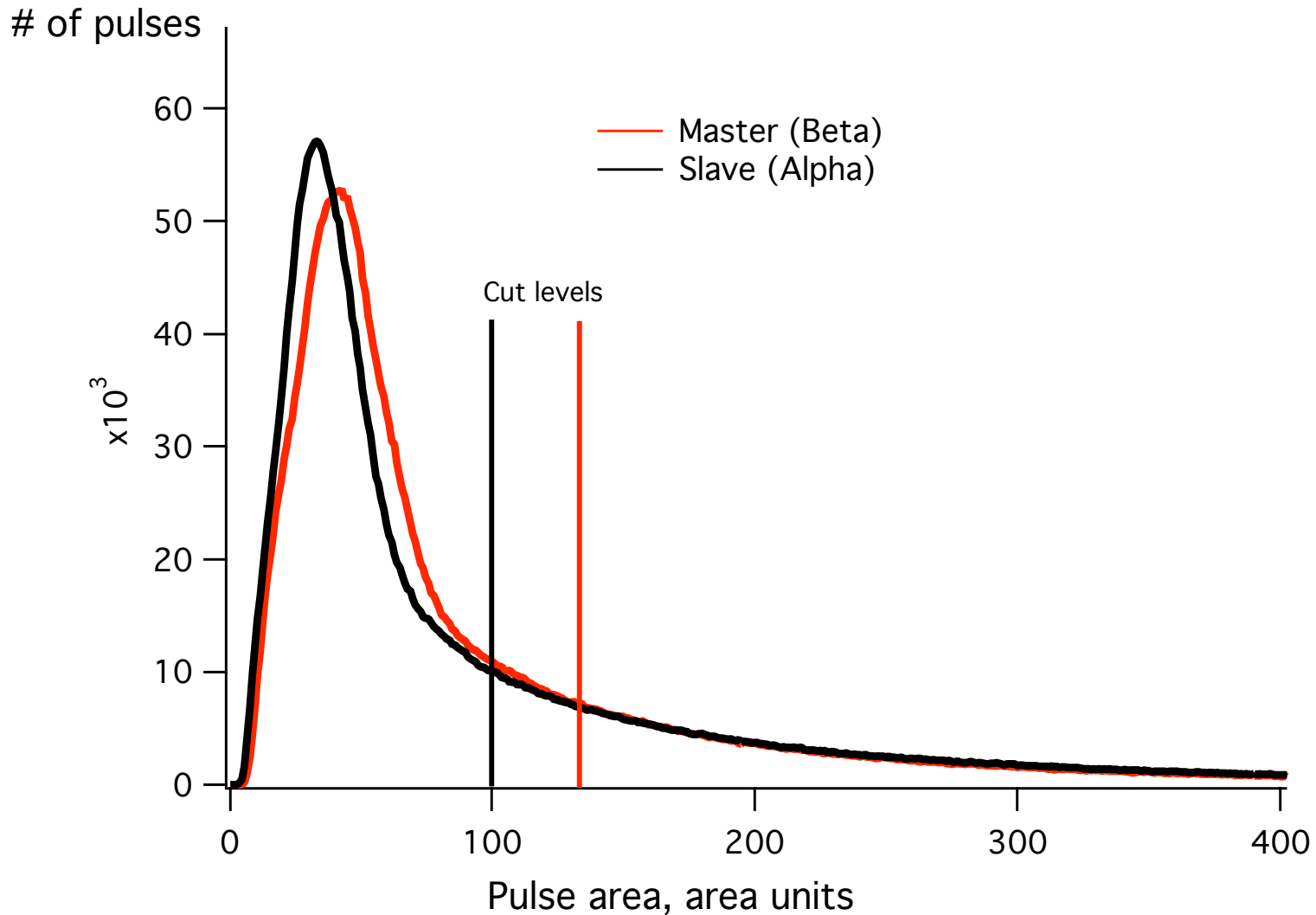
\therefore transmission $\approx 80\%$ at $T \leq 1\text{K}$ minus absorption in 2" of He when ^3He is present

Basic Idea of the Storage Experiment

- Measure the lifetime of UCN in the bottle at $T = 300 \text{ mK}$
- Rough estimate of $\sim 20 \text{ s}^{-1}$ neutron count rate, $\sim 20 \text{ s}^{-1}$ backgrounds
- Measure the lifetime of UCN in the bottle at $T = 1.2 \text{ K}$ (basically a measurement of the backgrounds)

Nomenclature

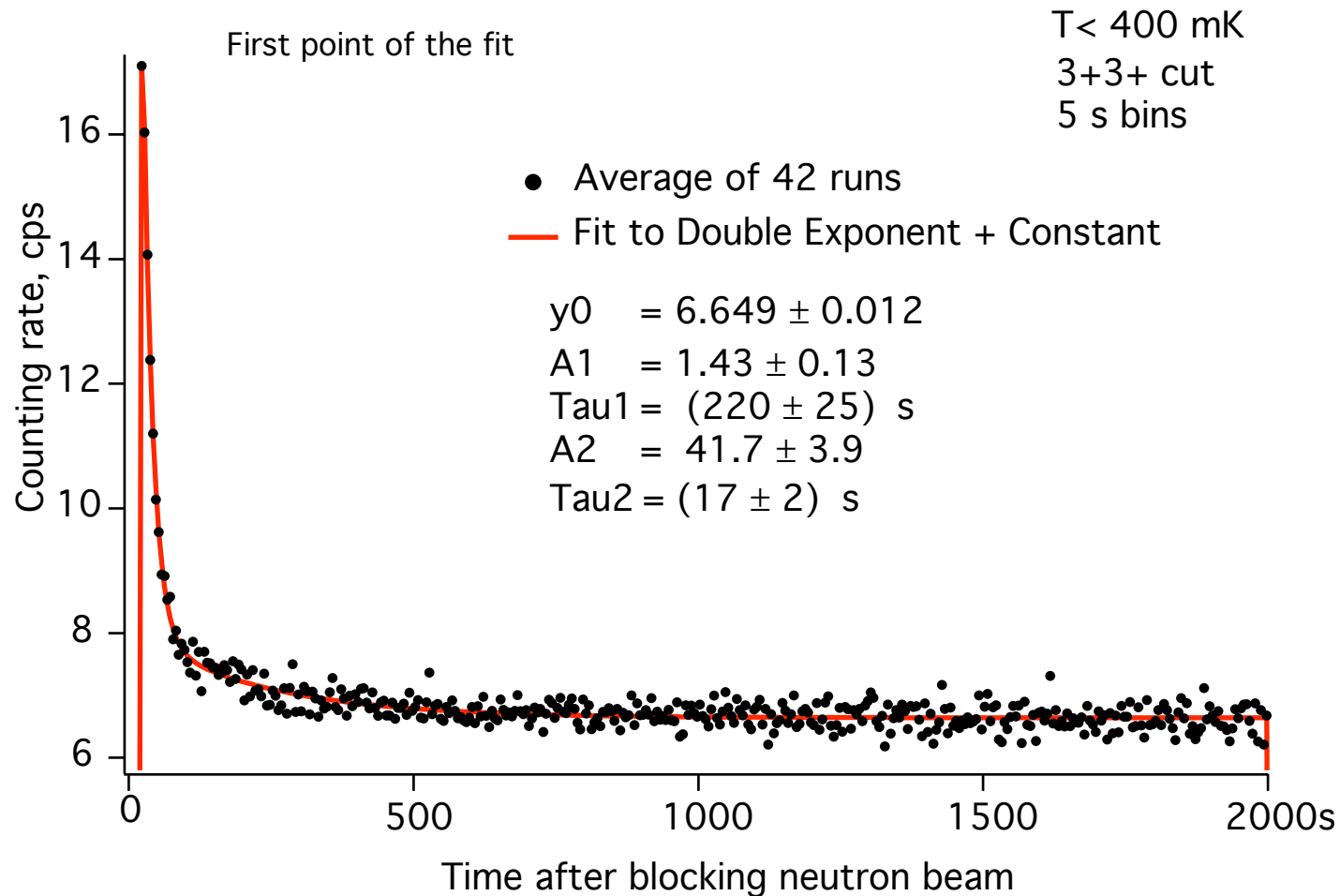
Pulse - height spectra of cell PMTs



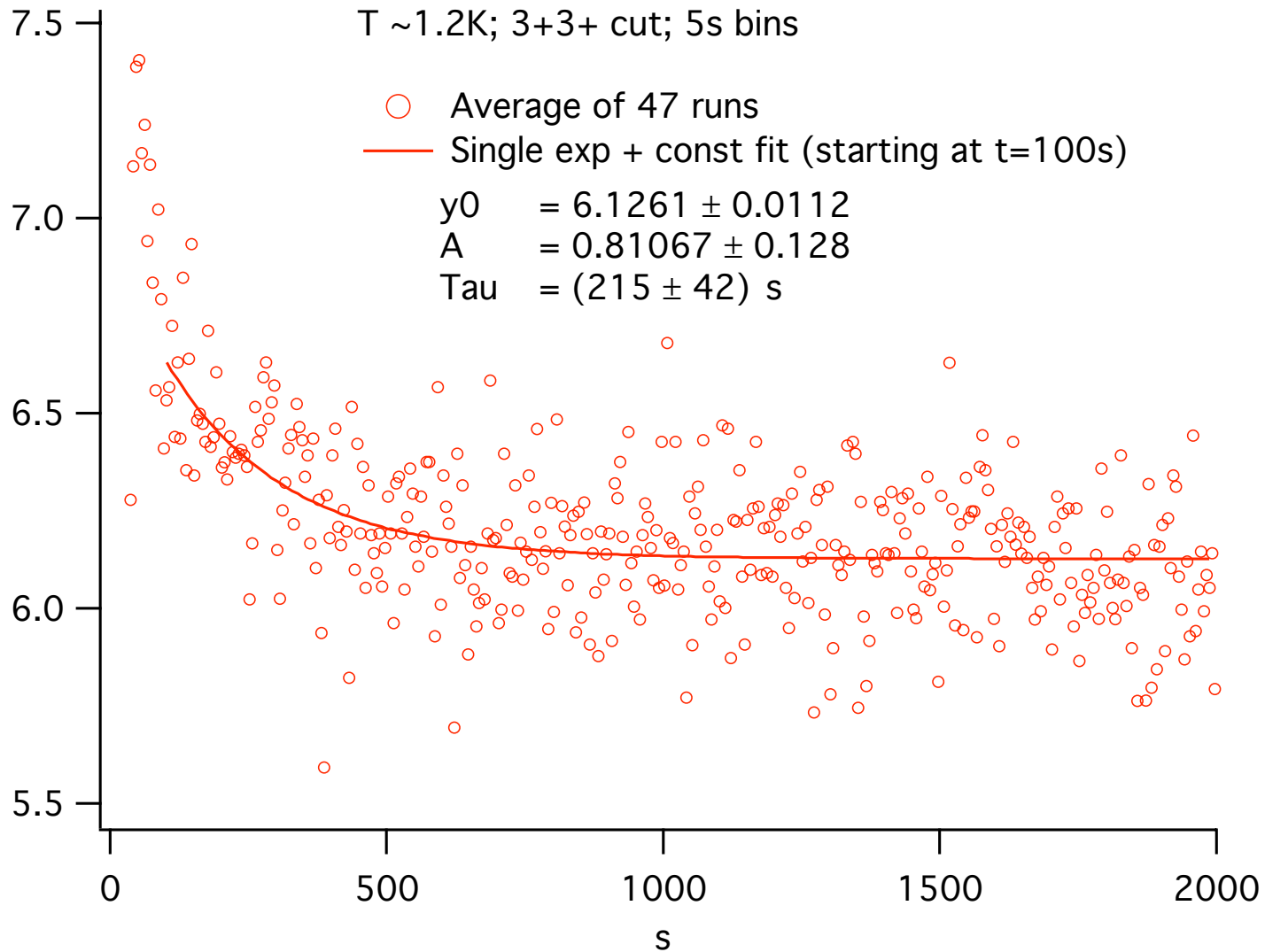
“Cold” Data

Run conditions:

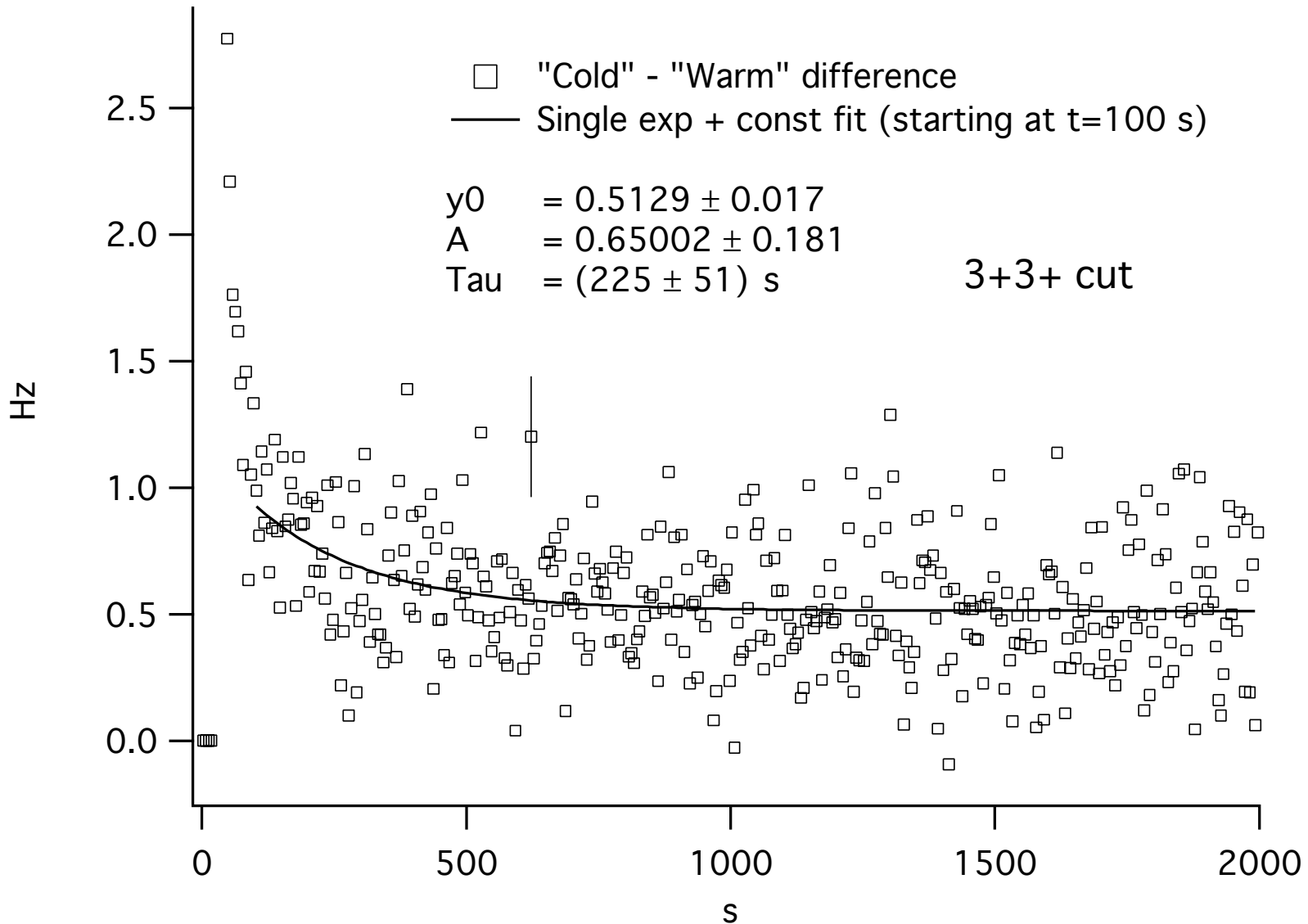
- Loading for 900 s
- Observing for 2000 s



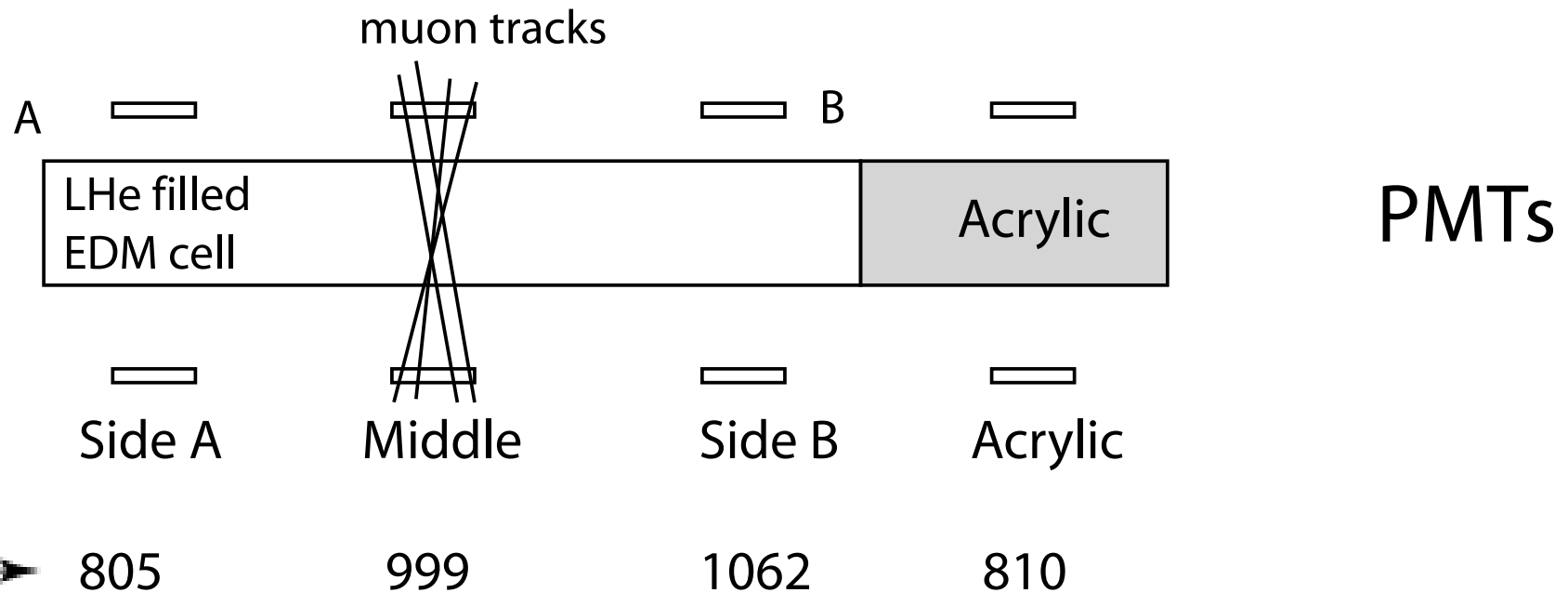
“Warm” Data



“Cold” - “Warm”

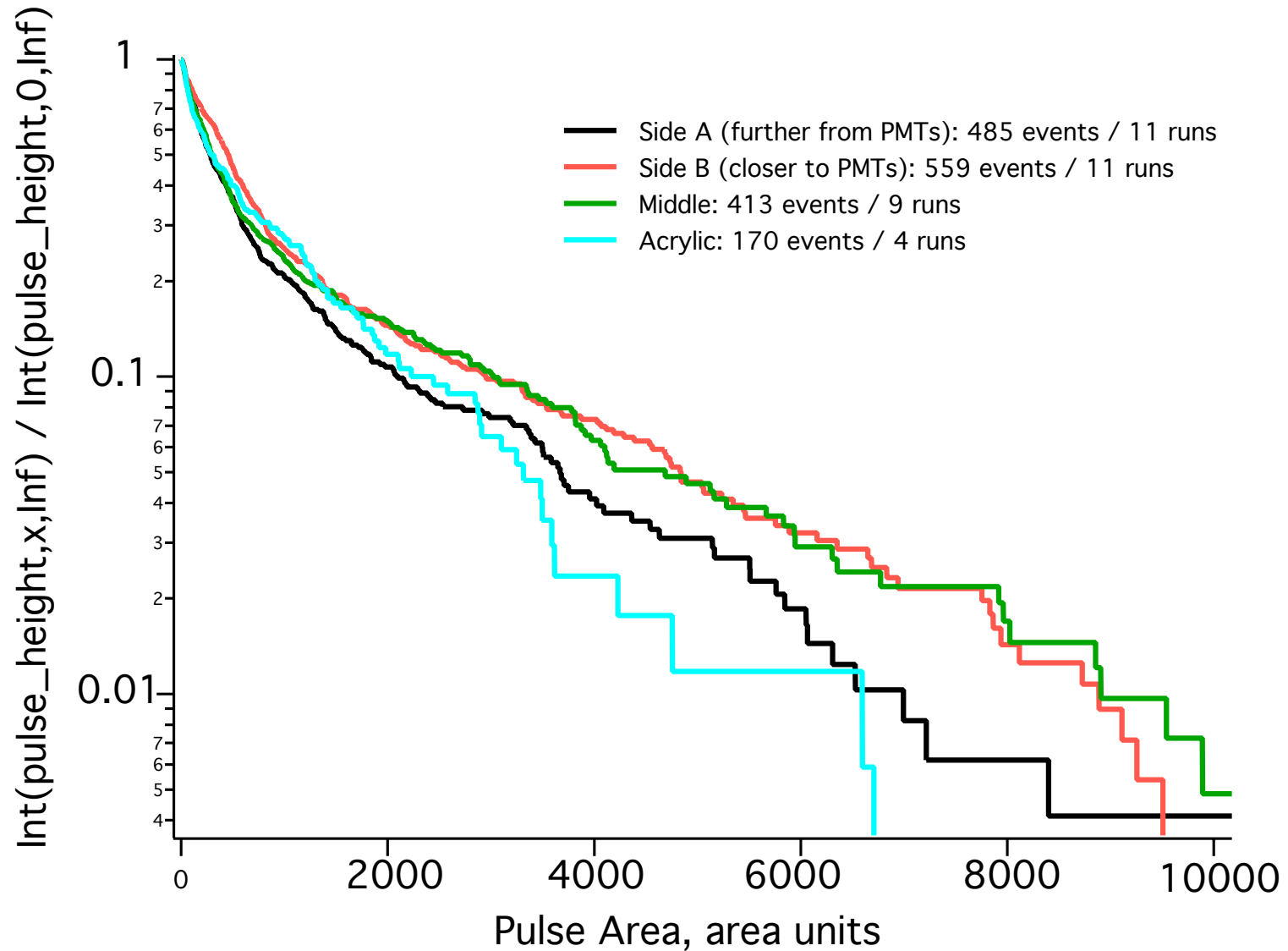


Rough Calibration

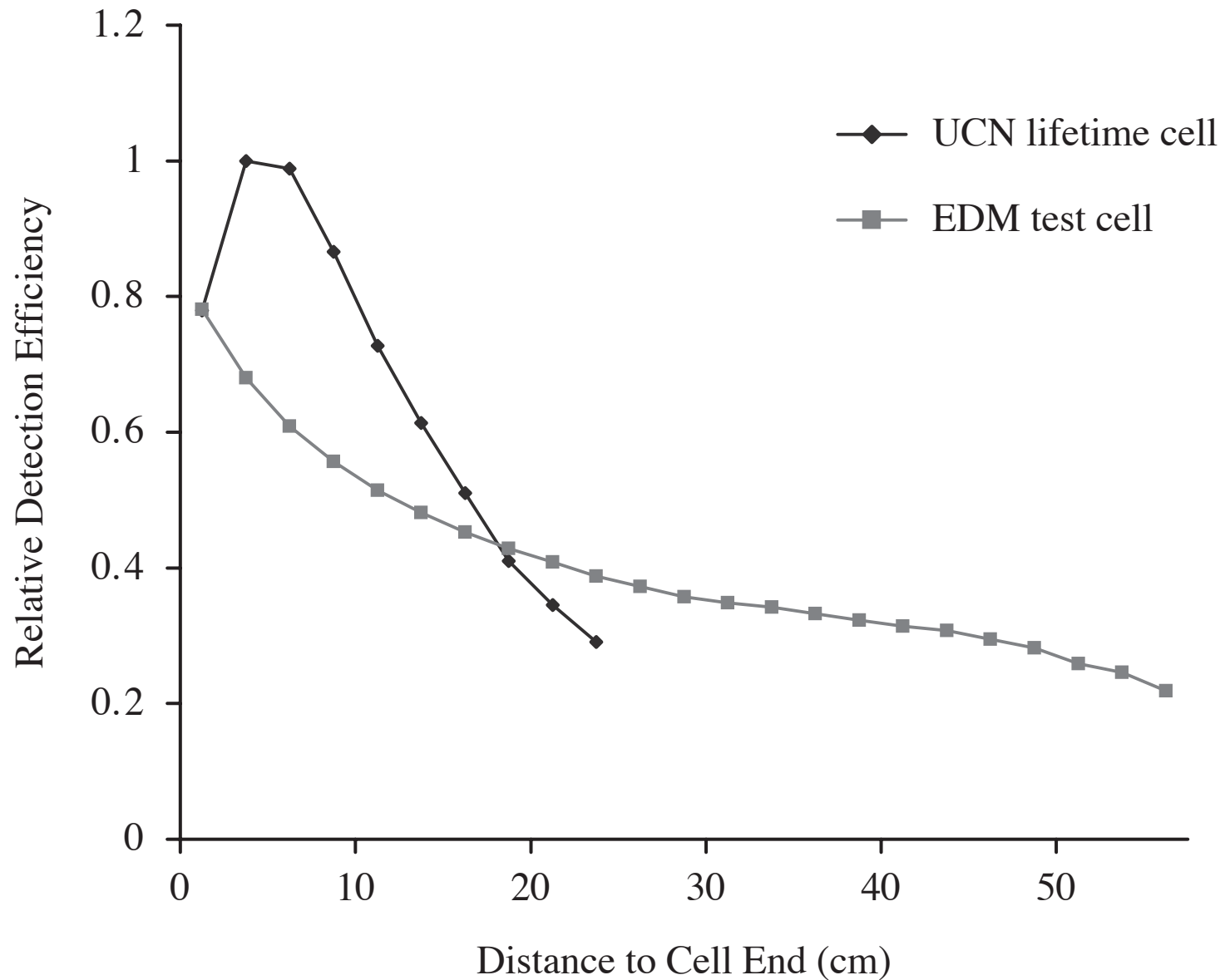


Average pulse size (in area units), requiring quadruple coincidence between two cell PMTs and two muon detectors

Pulse Areas



Ar gas calibrations



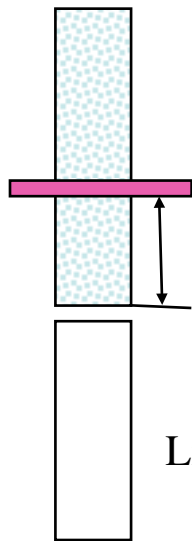
Discrimination Technique

Basic idea:

- neutron decay and background events generate scintillations via electrons
- neutron capture events generate scintillation events via alphas
- For a given pulse height for the singlet pulse, the number of triplet-state afterpulses will be greater for the neutron capture events.

HMI tests

PMMA cell coated
with the high
concentration (40%)
h-TPB, 1 mkm thick



Neutron beam
 ≈ 5 cm

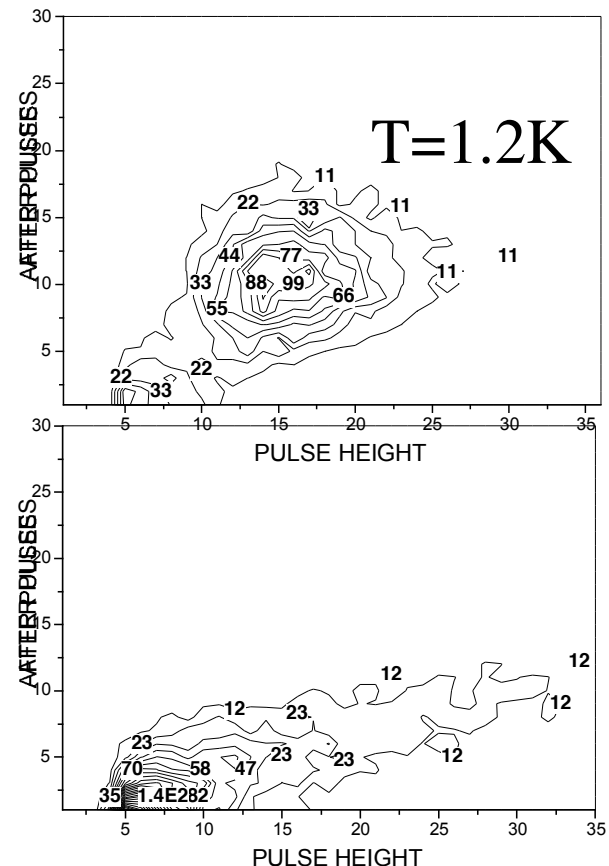
Light guide

Total count rate \approx few KHz,
20% of events with amplitude $A_m > 3 A_s$
of single pulses were selected for
analyses and shown on 2D plots
Neutron peak is ≈ 30 p.e. with ≈ 10
after pulses in the range $[0.5, 4.5] \mu s$

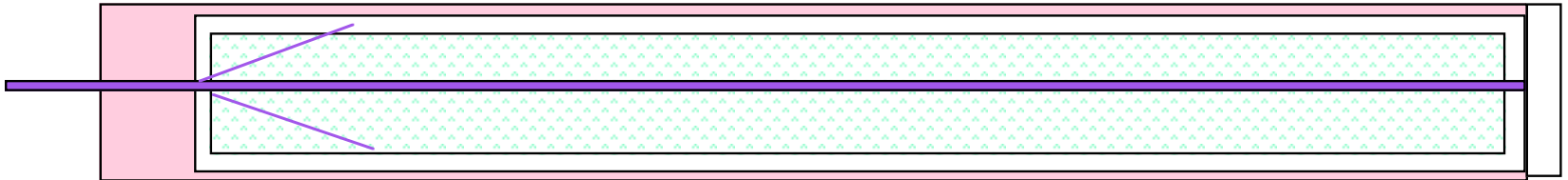
Clear separation of the neutron (top) and gamma's was
observed for solution of

${}^3\text{He}$ 1% + ${}^4\text{He}$ 99%

And for the beam position fixed relative to the light guide



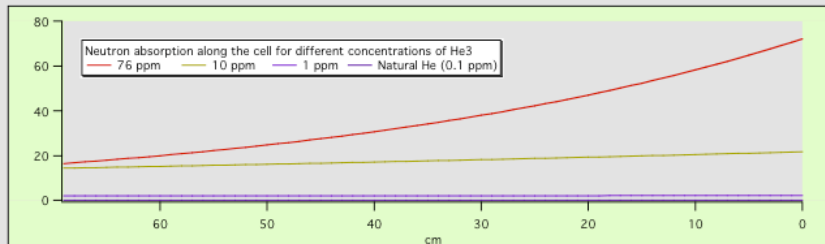
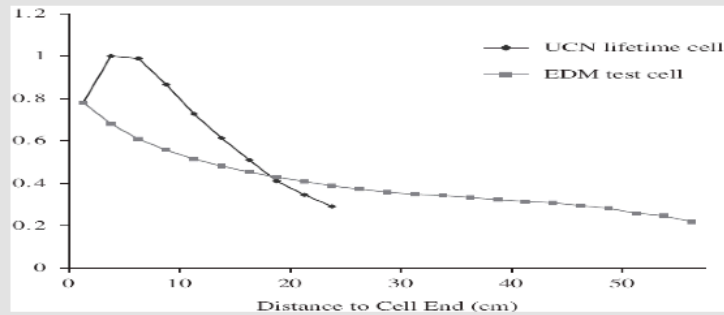
NIST run



Measurements performed at:

- $T = 4 \text{ K}$, empty cell, count rate 80 s^{-1}
- $T = 1 \text{ K}$, isotopically pure ^4He , 120 s^{-1}
- $T = 700 \text{ mK}$, different ^3He concentrations:
 - natural He ($10^{-7} \text{ } ^3\text{He}$), 140 s^{-1}
 - slightly more ^3He , 145 s^{-1}
 - $\approx 76 \text{ ppm}$ of ^3He , 450 s^{-1}
- Count rate with the beam closed with Li-rubber - 40 s^{-1} (mostly due to muons, no veto)

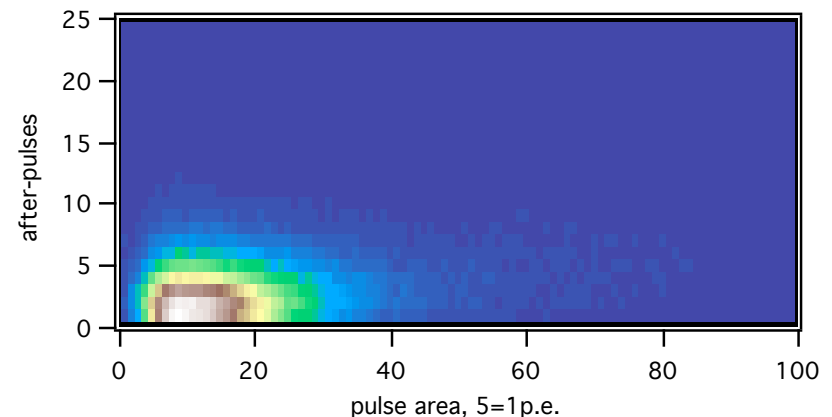
Geometry of the cell and efficiency of registration



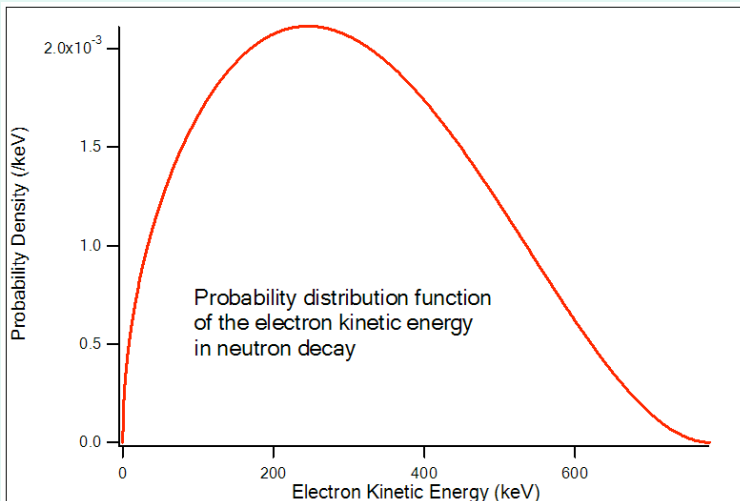
It is clear that pulses with area < 20 come from the far half of the cell. Probability to detect after-pulses is negligible.

Efficiency was measured in the test cryostat with Ar gas, 0.33 bar, ^{41}Am alpha source, $E \approx 5.5 \text{ MeV}$, alpha range $\approx \text{cm's}$, in LHe - mkm's

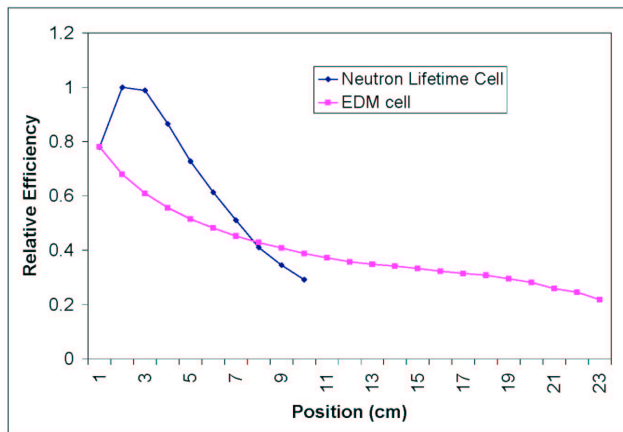
With 76 ppm of ^3He only small neutron pulses were seen by the detector. In addition the dead time (300us for periodic $\approx 3 \text{ ms}$ for statistical signal) was too long to count all signals.



Monte Carlo Simulation of Detection Efficiency



- First, a neutron energy is random generated according to the energy distribution function
- Secondly, the position of the neutron in the cell is randomly generated.
- From calibration data on the position dependence of the detection efficiency, we can scale to get the average number of p.e. in each PMT.
- We model the pulse height spectrum in each PMT with a Gaussian function, and integrate the total area above the require threshold, this represents the probability that this event will be detected by this particular PMT.
- Finally we multiply the detection probability in the two PMTs, then average over all randomly generated decay events.



The calculated detection efficiency:

Neutron Lifetime cell: 65% at 3 p.e. cut

EDM cell : 60% at 2 p.e. cut

Background and ^3He signals

Empty cell,

$T = 4\text{K}$,

count rate 80 Hz,

scintillations in PMMA

Ultra Pure Helium-4,

$T = 1000\text{ mK}$,

count rate 120 Hz=

scintillations in PMMA 80Hz +

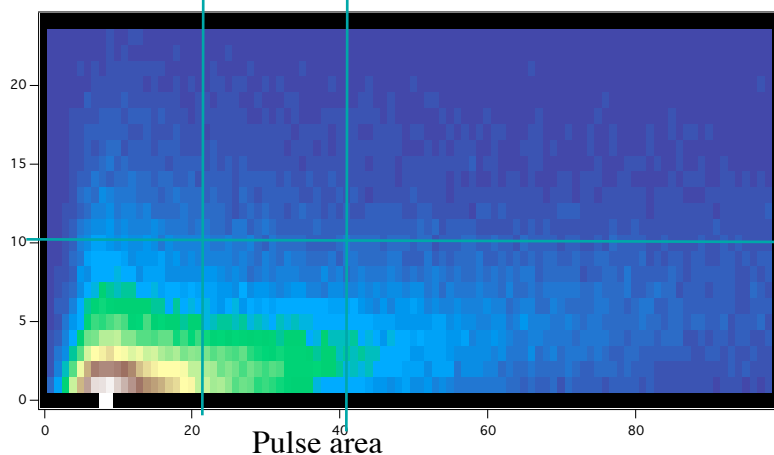
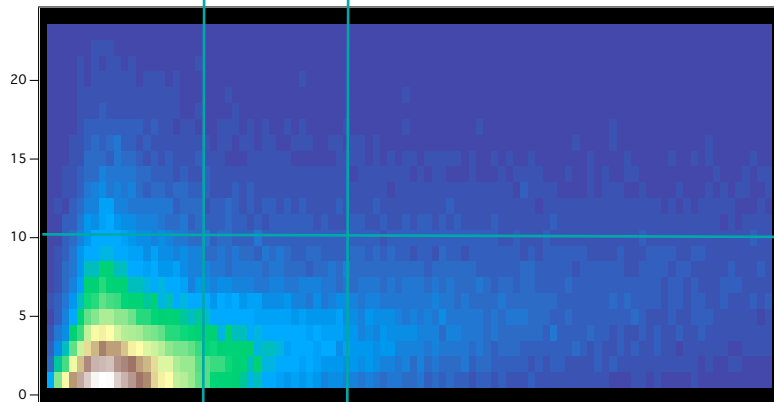
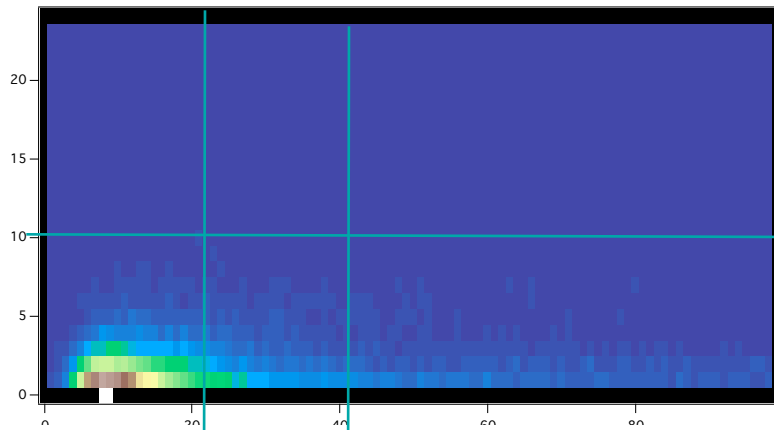
scintillations in LHe 40 Hz

Helium-4 + He-3 (appr. as Natural mixture, few 0.1 ppm),

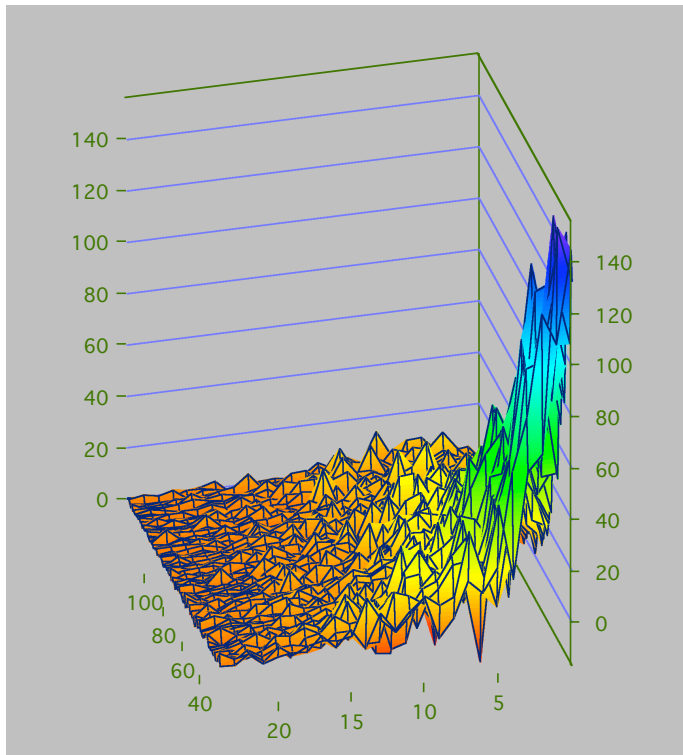
$T = 700\text{ mK}$,

Total count rate 145 Hz,

Neutrons 25 Hz



Neutron signals



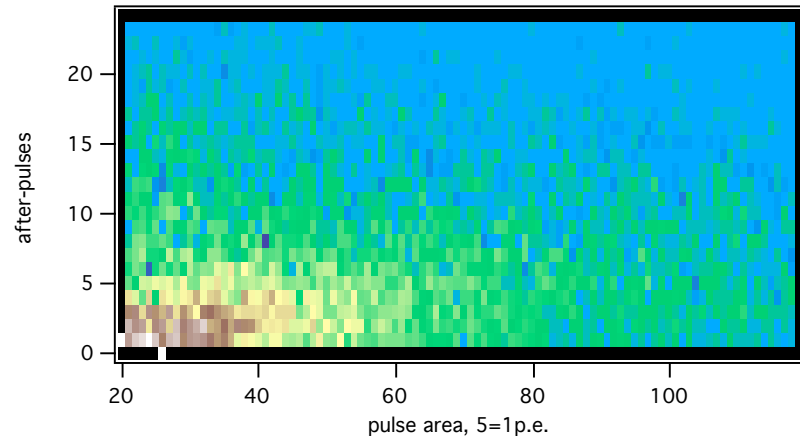
3D and 2D plots show difference

(few 0.1 ppm) - (Ultrapure ^4He),

(strictly speaking, it is not correct due to possible temperature dependence of amplitude and after-pulsing rate)

Pulse area is plotted above 20 = 4 p.e., i.e. assuming signals from the half of the cell closer to the light guide

Neutron signals have maximum peak at 8-10 p.e. (30 p.e. at HMI) and 2.5 after-pulses (10 at HMI)



Conclusions

- The neutron count rate (He-3 concentration), lower limit for the main pulse (too low), triggering time (too long) were not optimal for the study as well as cell geometry (too long). *The clear separation of the neutrons and background was not observed in this test.* The amplitude of the neutron signals (in p.e.) and number of after-pulses are at least ≈ 3 times less than at HMI.
- Possible reasons are
 - temperature dependence of the main pulse amplitude and after-pulsing rate (will be studied in more simple geometry at HMI , at temperatures down to 300 mK)
 - broadening of the neutron peak towards lower amplitudes due to geometry (the cell of EDM proposal is shorter and wider (50x10.2x7.6 cm) that studied at NIST)
 - TPB coating of HMI and NIST cells were made with different techniques and different content of TPB; also the thickness is very different (<1 mkm at HMI, 10 mkm test cell). Probably the detection efficiency could be increased by optimization of the coating.